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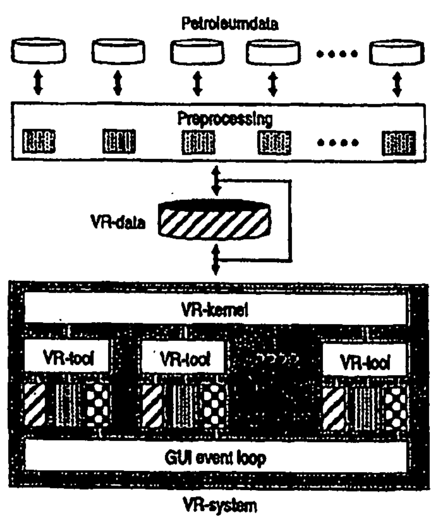

The main components of the proposed system architecture.

(57) Abstract

Method for visualization and analysis of volume data, particularly related to petroleum exploration and production planning, including means for storing, processing and visualization of the data. Within the total volume of three dimensional data, for instance seismic data, one or more volume windows are created which can be interactively and in real time moved around in the entire data volume and viewed from different positions and at different angles. By color and opacity manipulations the data inside the volume windows are made transparent, thereby allowing for a realistic time visualization of selected target positions of the data sets.

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METHOD FOR VISUALIZATION AND ANALYSIS OF VOLUME DATA

The present invention relates to a method for visualization and analysis of volume data, particularly related to petroleum exploration and production, including means for storing, processing and visualization of the data.

Introduction

Over the last few years the development of new data acquisition technology has encouraged the petroleum industry to move to areas of high geological complexity. Simultaneously, advanced drilling technology has enabled commercial exploitation of the hydrocarbon reserves in such areas. In mature areas, the undiscovered traps are expected to be small and heterogeneous. The oil production will take place with more use of horizontal and multibranched wells, and there will be stronger demands to increase the recovery factor. Therefore, the great challenge in the future will be to map such areas in finer details than previously, so that one can establish reliable reservoir models and carry out precise drilling.

As a consequence of the above, several work processes within E&P need to be improved. In *seismic interpretation*, new ways of extracting more information from the seismic data need to be developed. In *reservoir modelling*, more accurate simulation models are needed. In *well planning*, the positioning of new wells must be more optimal. In addition, data integration and interdisciplinary collaboration will be of increasing importance.

The work processes mentioned above all include analysis of large 3-dimensional (3D) datasets. The analysis is normally done by experts working on graphical work stations. The graphical workstations suffer from several weaknesses :

* It is often difficult to get a good understanding of complicated 3D data on a flat screen.
* It is laborious and difficult to interact with 3D objects by means of keyboard and 2D mouse.

* Analysis of 3D datasets are often done on 2D slices through the data cube.
* The screen size limits the amount of information that can be presented.
* A graphical workstation is designed for one single user.

Virtual Reality (VR) technology adresses these weaknesses and can improve the work processes mentioned above. VR technology will allow the professionals to :

* Interpret objects, model object, or plan production processes while being "present" in data space.
* Navigate in data space by use of natural body movements.
* Define, grab, and manipulate objects with natural arm and hand movements
* Perform interdisciplinary collaboration in a shared virtual environment.

The invention adresses one important challenge by introducing VR in E&P, that is to find effective ways for visualising large amounts of volume data in real time

Summary of the invention

The methods which have been developed previously for direct volume rendering of seismic data and geological models are not well suited for use in virtual reality systems. The reason for this is that the size of the datasets generated by the present acquisition and modelling systems are too large to be visualized by a computer in real time. With real time visualization we mean that any changes in the object to be visualized will be immedeately and correctly displayed on the display unit, e.g. a graphic screen. With real time visualization, the computer must be able to update and redraw the object on the display unit at a rate of minimum 10 - 15 times per second.

In order to obtain simultaneous visualization of volume data and other types of data in real time one should avoid that all data are shown at a time. This can be achieved by :

* Slicing through the volume dataset with an opaque plane. With this method, no semi-transparent volume data can be shown.

* Resampling of the volume data to a courser grid. With this method, valuable information may be lost.
* Selecting a limited part of the volume data and show this in full resolution. This solution makes it difficult to move dynamically between different parts of the volume dataset.

With the present invention a method is provided by which it is possible to select and process a data set by forming a Real time Volume Window (RVW). More precisely the invention is characterized in that, within the total volume of three dimentional data, one or more limited volume windows are created which can be interactively and in real time moved around in the entire data volume and viewed from different positions and at different angels and whereby, by color and opacity manipulation, the data inside the volume windows are made transparent, thus allowing for a realistic real time visualization of selected target positions of the data sets.

Independent claims 2 - 13 define advantagous features of the invention.

RVW is an alternative to the methods listed above. With RVW, semi-transparent data can be shown within a 3-dimensional window (volume window) with dimensions defined by the user. The volume window can be moved around interactively in the total volume dataset in real time.

RVW is a flexible method which is assumed to be of significant importance in future virtual reality systems within the oil and gas industry. Simply by adjusting the window parameters, the concept allows for adaption to any size of seismic datasets or machine computing power, so that real time responses are achieved.

Several important applications of RVW can be found within the field of oil and gas exploitation, such as visualization of seismic data, interactive region growing of seismic data and interactive well planning.

RVW is implemented as a plug-in in an open system without the loss of performance.

RVW has generalized window parameters, i.e. the size and resolution of the volume windows, together with selection of dataset and colour parameters can be adjusted interactively by the user.

RVW has generalized window orientation. It may either have a strictly view dependent (VD) orientation, or it may have a spatial mouse (SM) dependent orientation. In both cases the RVW is drawn using texture based volume rendering with planes perpendicular to the viewing direction. These options will be described in more detail in the next section.

Several RVW's can be used simultaneously in a virtual reality system, with different datasets in each volume window.

Description of the method

The invention will be further described in the following by way of example and with reference to the drawings where,

Fig. 1 shows the main componets of the system architecture by which the method is performed,

Fig. 2 shows a flowchart for real time volume windows according to the invention,

Fig. 3 shows a flowchart for interactive well planning based on RVW,

Fig. 4 is an image of a geological formation depicting a volume window in centre.

Fig. 1 shows, as stated above, the main componets of the system architecture for the method according to the invention. The system, operated by the end users (geoprofessionals), is provided through algorithms, to preprocess the petroleum input data from a storing medium into formats or datastructures (VR-data) suited for real time rendering. The preprocessing may include:

- Generation of multiresolution geometric models through spatial subdivision,

simplification and/or aggregation.

- Creation of graphical primitives particulrly suited for fast rendering, e.g. triangle strips and textures.
- Performing image processing and compression of volume data.
- Performing teplate oriented editing of initial visualization parameters (e.g. color and opacity).
- Creation of default coupling to a VR-tool.
- Verification of VR-data.
- Printing of graphical model statistics and predicted response times in specific virtual environments.

The system kernel manages rendering and state changes in different VR-tools, while the general user interface (GUI) event loop submits messages to the command interpreter in the VR-tools (indicated by the black pattern in Fig. 1). The different VR-tools represents a set of related analysis algorithms that operate on specific VR-data, and an editor for parameters associated with these algorithms. In this context, analysis refers to both rendering and interactive modelling or interpretation af data. Examples of different tools may be "path tool" to show well paths and reveal well log information; "slice tool" to show opaque colored slices and "volume window tool" to show and open one or several windows, drag window etc.

An overview of the RVW method is given in the flowchart in Fig.2. A description of each individual process in the flowchart is given below. The processes are referred to as RVWj, where j is the number indicated in each box in the flowchart.

RVW visualizes volume data by drawing a set of slices or planes through the volume. The planes always have an orientation perpendicular to the viewing direction. The planes can be made transparent, thus one can look into the volume and not only on the plane closest to the users eyes.

Data are mapped to each plane using texture mapping. In RVW, this can be done in two different ways. The first method is software based and the textures are calculated by slicing the volume data in software. The second method is to load the entire data set into texture memory of the computer, and leave the texture mapping to the rendering hardware.

The RVW involves the use of several different coordinate systems as desribed below. The system calculates and stores the matrixes needed for transforming data between these coordinate system.

Coordinate systems

* World coordinates	A common coordinate system for all the datasets included in the system. Most often this will be UTM coordinates.
* Data set coordinates	Specific coordinate system for each idividual dataset. For seismic datasets, these coordinates will normally be defined in terms of inline number, crossline number and timeslice number in the x, y, and z direction respectively.
* Texture coordinates	The coordinate system for the texture memory in the computer. Describes where the data is stored in computer texture memory.
* Device coordinates	The coordinate system for the display device where the data is finally visualized. For an ordinary computer screen, the device coordinates will range from 0 to the size of the screen in the x and y direction respectively.

Process description (ref. flowchart in Fig. 2)

RVW1 A computer program reads 3D seismic datasets into computer memory.

RVW2 The computer program initialises a list of volume windows to be maintained and resets the counter for the number of volume windows to be generated.

RVW3 The user of the RVW system defines following parameters :

- horizontal size of volume window
- vertical size of volume window
- depth of volume window
- resolution in volume window (in number of pixels)
- dataset to be visualized in the volume window
- colour and opacity tables to use for the volume window

The parameters are read by the computer program.

RVW4 The user of the RVW system defines an initial position of the volume window by use of a pointing device such as a spatial mouse. The computer program then reads the position and creates the volume window at that position.

RVW5 The computer program inserts relevant information about the volume window in a list of volume windows to be maintained by the computer.

RVW6 The computer program checks if the user wants to create more windows by checking the status of the users spatial mouse.

RVW7 The computer program receives the users eye position and viewing direction from the tracking system.The information comes from a sensor near the eyes of the user. This sensor is connected to the tracking system, which continuously delivers updated viewing parameters to the application. These data are defined in device coordinates.

RVW8 The computer program initializes the loop that draws all volume windows in the window list (see RVW5).

RVW9 The computer program receives any changes in the position and orientation of the volume window. The position can be continuously changed using a spatial mouse. The orientation of the volume window may be independent of the viewing direction. In this case, the orientation can be changed by using the spatial mouse (SM orientation). The window can also be oriented in a view dependent direction (VD orientation). The orientation is then calculated so that the window is perpendicular to the viewing direction, see RVW7 above. In both cases, the planes inside the volume window are oriented perpendicular to the viewing direction. See Fig. 1.

RVW10 The computer program register changes in the parameters for the volume window, see RVW3. Some parameters can be changed based on the viewing direction and by using the spatial mouse, see RVW9. Additional parameters can be changed using a menu system or voice input.

RVW11 Every time a change occurs in position, viewing direction or other

viewing parameters for a volume window, one or more of the following is done:

1. The computer program calculates the position and orientation of the planes in the volume window (perpendicular to viewing vector). For VD orientation, the volume window itself is also oriented perpendicular to the viewing vector.
2. For each plane in the volume window , the computer program calculates the position for lower left corner in addition to two vectors describing the orientation and size of the plane.
3. For software based volume rendering, the point and vectors (see point 2) are input to the computer program that calculates the texture of the plane from the volume data. The method used is trilinear interpolation, and it calculates a 2D slice through the data given by the input plane specification.
4. For hardware based volume rendering, point 3 is automatically done by the computer hardware.

RVW12 Drawing of the volume windows includes the following steps carried out by the computer program:

1. Select blending parameters and load the appropriate transformation matrixes.
2. For each plane do:
   - 2.1 Calculate the corner coordinates in world coordinates.
   - 2.2 For software slicing, load the appropriate texture.
   - 2.3 Calculate the texture coordinates for each corner of the plane.
3. Select appropriate drawing sequence, usually from back to front.
4. Draw the planes.

RVW13 The computer program checks if the user wants to delete the window by checking the status of the spatial mouse.

RVW14 The computer program deletes the window

RVW15 The computer program deletes the window from the list of windows to be maintained.

RVW16 The computer program selects the next window to be drawn from the list of windows to be maintained.

RVW17 The computer program checks if the end of the list of volume windows to be maintained is reached.

RVW18 The computer program checks if the application is to be finished by checking the status of the spatial mouse. If not, control is given to RVW6.

Applications of RVW

Below is listed some of the applications of the RVW method in petroleum exploration and production.

Viewing of 3D seismic data

Viewing of 3D seismic data is traditionally done on graphical workstations, either by looking at 2D slices cut through the 3D data volume or by visualizing a complete 3D data cube. By the first method, you loose the 3-dimensional aspect of the data. In the second method it is normally impossible to obtain real time

response times due to the size of most 3D seismic datasets and the limitations of todays computers.

The RVW comprises a method for viewing 3D seismic data in a virtual environment where both the 3D perspective and real time response times are obtained. In RVW, the size of the input 3D dataset is limited only by the amount of RAM in the computer. By placing a volume window inside the 3D dataset, a limited part of the seismic data can be viewed in full resolution. Different parts of the data can be viewed by interactively moving the volume window by use of a spatial mouse. In this manner, it is possible to get better understanding of geological features contained in the 3D seismic data. Such features may consist of everything from large scale structures like geological horizons and faults, via medium scale events like channel structures and sand lenses, to small scale internal reflection patterns.

Interactive region growing

The RVW can be used as a tool for volume detection by means of region growing. The volume window limits the area in which the region growing is performed. The position, size and orientation is controlled by using the spatial mouse (SM orientation). A seed point for the region growing is defined and placed within the window using the spatial mouse. Threshould values for the region growing are also defined.

The user controls the region growing by using buttons on the spacial mouse, a menu system or voice input.

The data points detected by the region growing process are visible instantaneously because the algorithm directly updates the data set that is loaded into texture memory of the computer. By altering the colour table, one can choose to see only the detected data points, or the detected data points in combination with the

original data set. One specific colour in the colour table is allocated to the detected data points.

When region growing is finished inside the volume window, the volume window can be moved by the spatial mouse and the region growing can be continued. The new seed point will then be the last data point that was detected in the previous position of the volume window.

The detected data points are buffered to support undo and redo functionality.

Interactive well planning

A method for interactive well planning in a virtual environment is sketched in the flowchart in Fig.3. The method can be used either to visualize existing well paths and log information or to design paths for new wells to be drilled. In this context, a well path is defined by a set of node points connected by a spline curve. A new well path is designed by pointing and clicking a spatial mouse at selected positions in 3D space. A new node point will be generated for each click.. The well path will be represented by a spline curve connecting the node points. The spline curve will be drawn in real time. An existing node point can be changed simply by grabbing it and move it to the desired posisiton with the spatial mouse. Similarly, an existing node point can be deleted. The spline curve will be updated in real time. When the generation of a new wellpath is finished, the coordinates for the node points are stored in the computer.

Information from seismic data is neccessary in order to position a new well at the correct location in space. This can be achieved by combining the RVW with the interactive well planning process in the following manner: One or more volume windows are placed in the area where the well is being planned. The positions of the volume windows are fine tuned until the seismic data inside the window clearly

reveals the drilling target. The target feature can be made more clear by changing the opacity curve for the window, e.g by making all datapoints in the volume window transparent exept the ones representing the target. Node points for the new well path can now be placed in the middle of the target by pointing and clicking the spatial mouse inside the volume window as described above. If the planned well path extends outside the volume window, the volume window can be slightly moved and the process repeated. An example of well planning with RVW is given in Fig. 4.

Claims

1. Method for visualization and analysis of volume data, particularly related to petroleum exploration and production planning, including means for storing, prosessing and visualization of the data,
characterized in that, within the total volume of three-dimensional data, for instance seismic data, one or more limited volume windows are created which can be interactively and in real time moved around in the entire data volume and viewed from different positions and at different angles and whereby, by colour and opacity manipulation, the data inside the volume windows are made transparent, thus allowing for a realistic real time visualization of selected target positions of the data sets.

2. Method, according to claim 1,
characterized in that the definition of the volume window and its parameters can be altered.

3. Method, according to claims 1 and 2,
characterized in that the size of the volume windows in the x, y, and z directions, respectively can be interactively adjusted.

4. Method, according to claims 1 and 2,
characterized in that color and opcity can be interactively assigned to the volume window and thereby obtaining colour contrasts and transparancies neccessary to study selected parts of the data volume.

5. Method, according to claims 1 and 2,
characterized in that the resolution of the volume windows in terms of number of pixels along the horizontal and vertical axes of the volume windows can be interactively selected.

6. Method, according to claims 1 and 2,
characterized by interactively moving the volume windows around within the total 3D data volume by use of a spatial mouse or similar device.

7. Method, according to claims 1 and 2,
characterized in that the data within the volume windows is visualized by drawing a number of parallel planes through the volume windows with orientations perpendicular to the viewing direction and mapping data to each plane using texture mapping.

8. Method, according to claims 1 and 2,
characterized in that two different modes (A and B) for visualizing the data within the volume windows are used, whereby in mode A both the volume window and the texture planes inside the volume window have an orientation perpendicular to the users viewing direction and in mode B the orientation of the volume window are locked in a user defined position while the texture planes inside the volume window have an orientation perpendicular to the users viewing direction.

9. Method, according to claims 1 and 2,
characterized in that several volume windows are displayed at the same time with each volume window containing data from the same or from different 3D datasets.

10. Method, according to claims 1, 2, and 9
characterized in that positioning of two or more volume windows are performed such that they completely or partly overlap in 3D space.

11. Method, according to claim1
characterized in that interactive real time region growing within a volume window is performed.

12. Method according to claim 11

c h a r a c t e r i z e d in that a seed point is interactive positioning within the volume window, and that specification of the range of data values are included in the region growing.

13. Method, according to claim 12

c h a r a c t e r i z e d in that the areal extent of the region growing is limited by means of a 3-dimensional box which is positioned inside the volume window whereby the size, shape and orientation of the 3-dimensional box can be interactively adjusted by means of a spatial mouse.

14. Method, according to claim 13

c h a r a c t e r i z e d in that the region growing is continued in any direction by moving the 3-dimensinal box in the wanted particular direction.

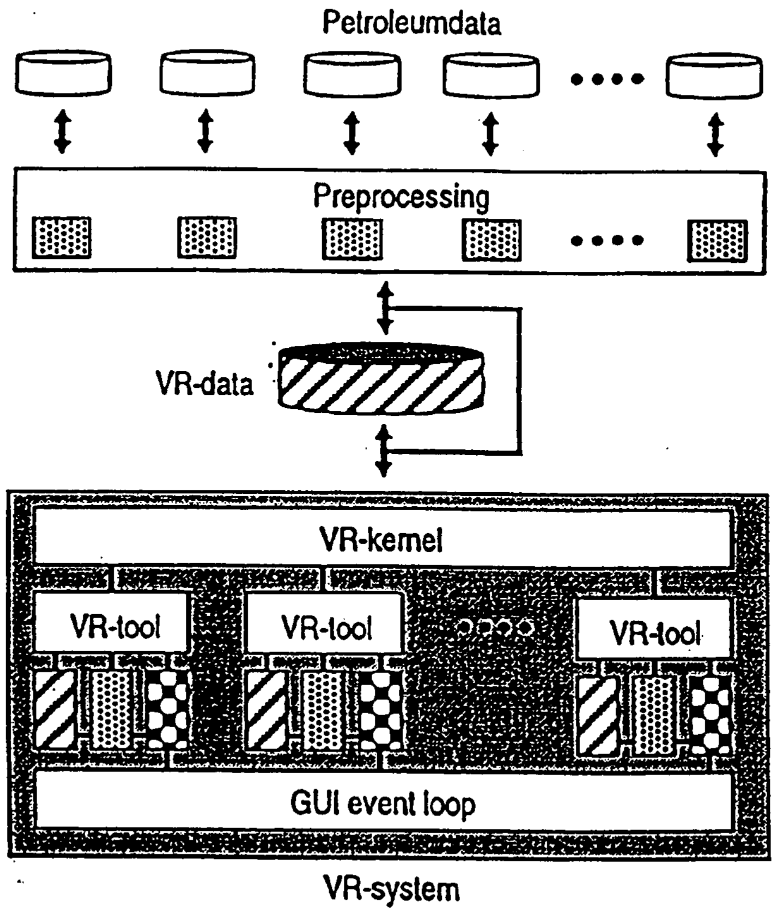

Figure 1 The main components of the proposed system architecture.

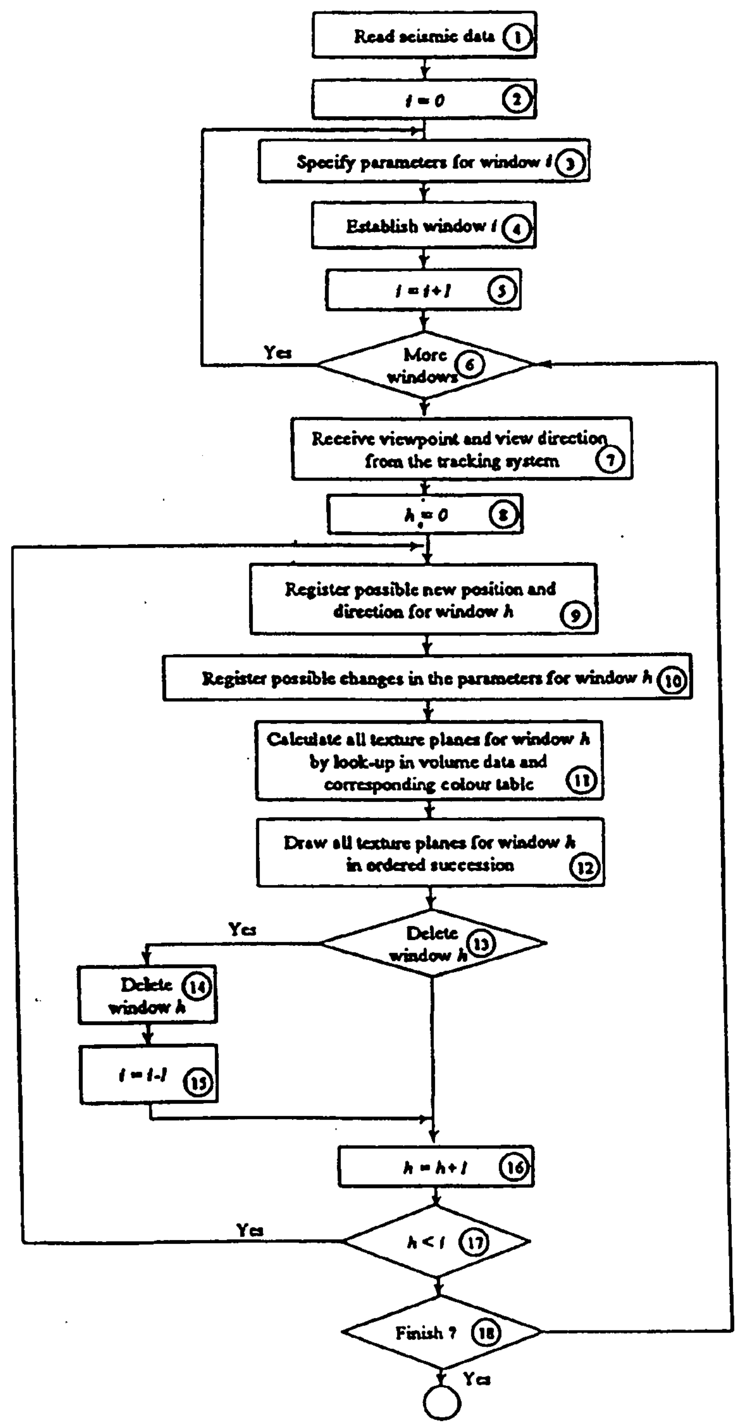

Fig.2. Flowchart for Real time Volume Window

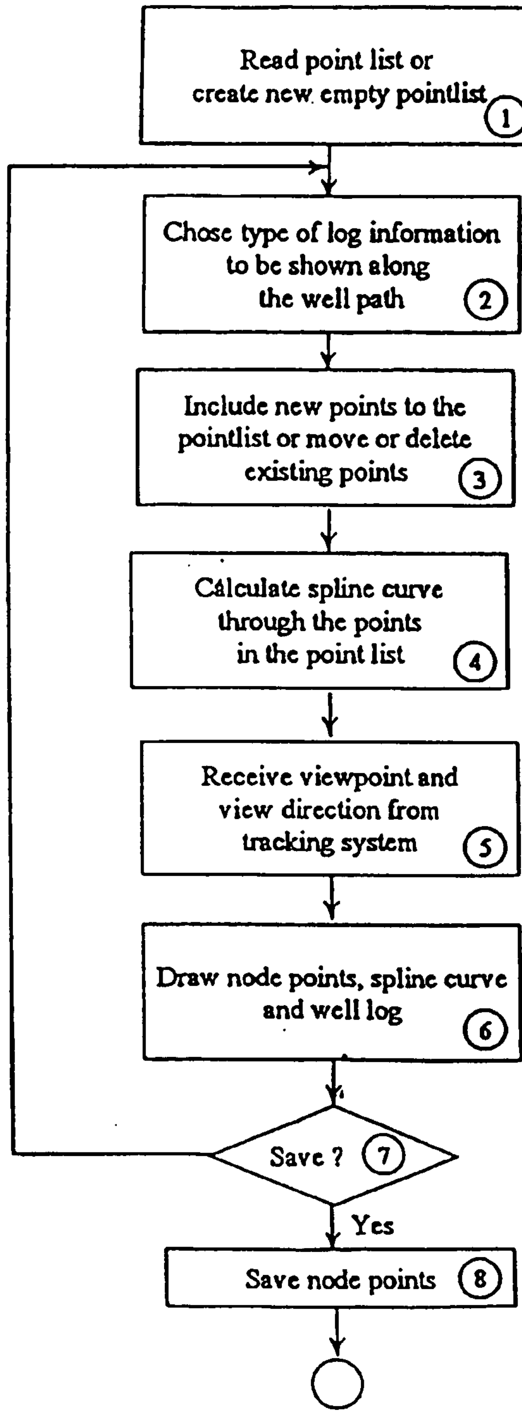

Fig.3. Flowchart for interactive well planning

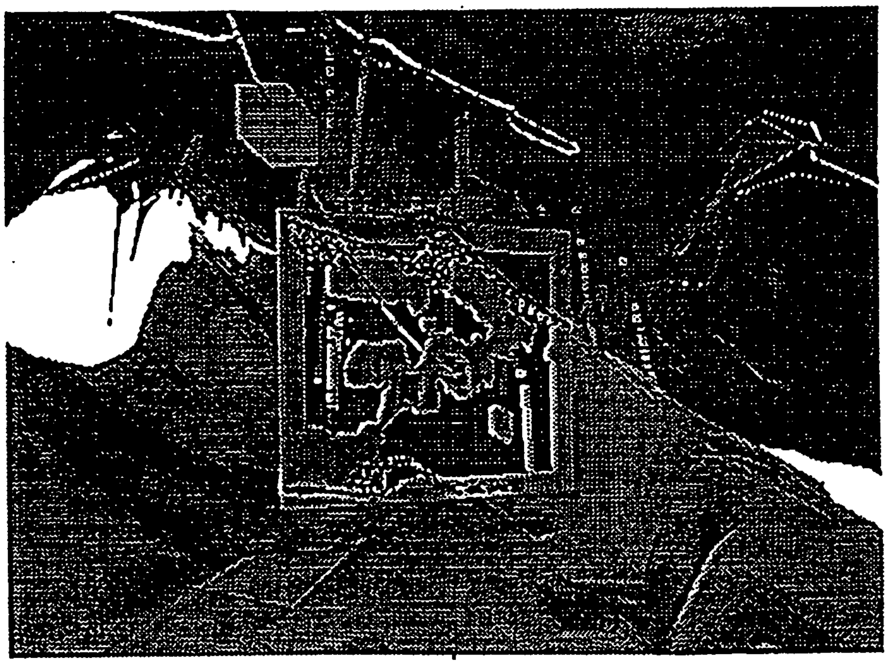

Fig. 4. Example of RVW in well planning. The volume window in center of the figure shows several channel like features. A horizontal well has been placed in the middle of the rightmost channel. Two geologial surfaces are also shown on the figure.

INTERNATIONAL SEARCH REPORT

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IPC7: G01V 1/28, G06F 3/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01V, G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5659691 A (J. DURWARD ET AL.), 19 August 1997 (19.08.97), column 1, line 1 - column 5, line 41; column 6, line 41 - column 7, line 46; column 8, line 15 - column 9, line 2, abstract --	1-6,9-11
A	WO 9618915 A1 (AMOCO CORPORATION), 20 June 1996 (20.06.96), page 1 - page 11, figure 1, abstract --	1-14
A	US 5759044 A (S. REDMOND), 2 June 1998 (02.06.98), column 1, line 19 - column 6, line 29, abstract --	1-14

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5574836 A (R.M. BROEMMELSIEK), 12 November 1996 (12.11.96), column 3, line 60 - column 4, line 49, figure 6, abstract -- --------	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

02/12/99

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